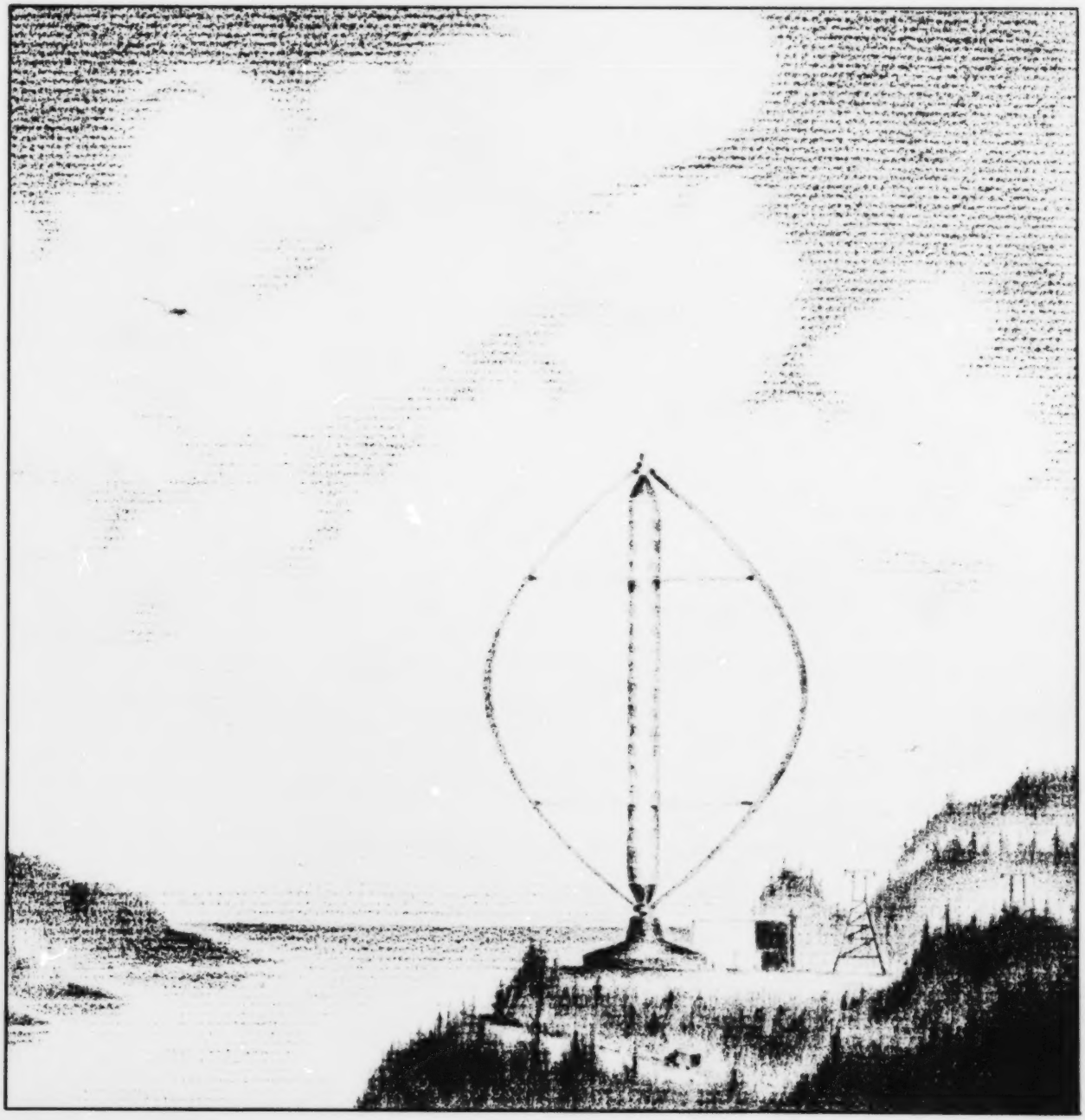
Exploring Energy - 1

Wind Energy



Canada

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Cover:

Large windmills such as that shown, erected wherever winds are strong and transmission lines near at hand, could provide up to 5% of all the electrical power now used in Canada.

Prepared for Energy, Mines and Resources Canada
and the National Research Council Canada
by Sean McCutcheon & Associates

Designed by Quorum Graphics
Print Production Coordinator: Robert Rickerd
Printed by Love Printing Services Ltd., 31025-0-0246

Special thanks to Jack Templin for sharing his knowledge

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ISBN 0-662-11120-6
Cat. No. NR53-2/1-1980E

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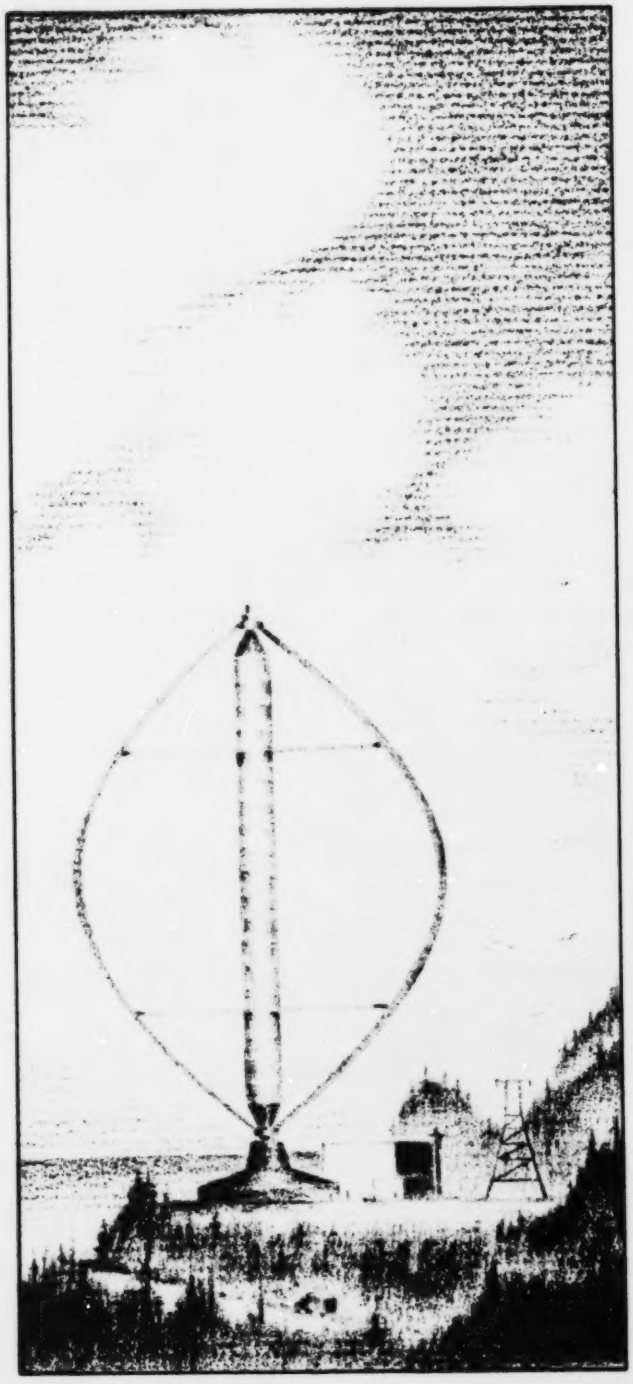
Wind Energy

by Sean McCutcheon
Illustrated by John Bianchi



Canada

Foreword

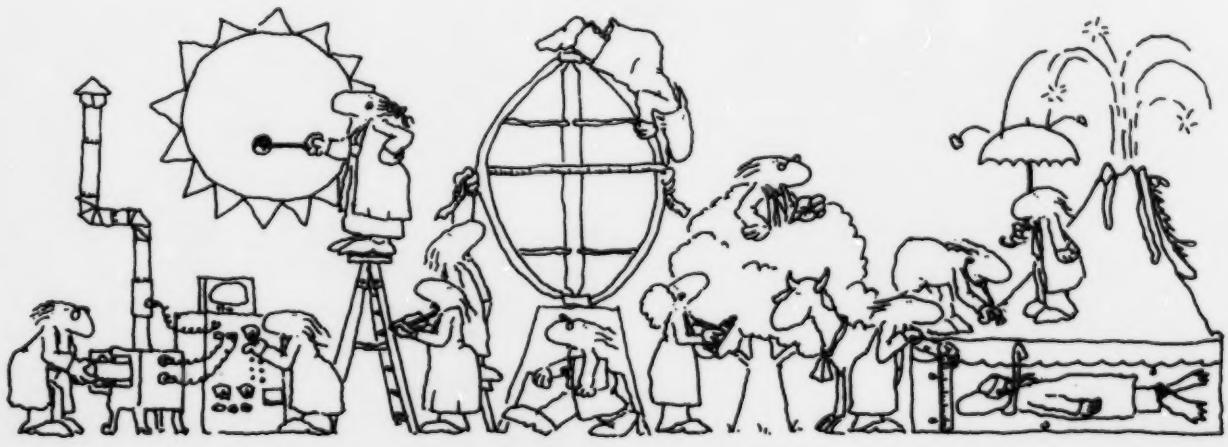
Canadians use a lot of energy. We have enjoyed plentiful supplies of cheap and convenient energy, principally in the form of oil, since the early 1900's. Our thirst for oil has exceeded our conventional oil supplies and we now import oil from other countries. Recent world events have made us realize the strategic and financial dangers of being dependent, as a nation, on others for such a vital commodity as energy. Moreover, the increasing world consumption of oil has emphasized the finite nature of these reserves. At current consumption rates, our grandchildren will live to see the last drop pumped out of conventional oil wells. Clearly, we must curb our appetite for energy, and we must learn to consume a wider variety of energy forms, even though they will be less convenient and more expensive than those we have become accustomed to.

In searching for alternatives to continuing dependence on finite energy resources such as fossil fuels, the desirability of renewable energy sources is obvious. Hydraulic energy already contributes significantly to our electricity supplies; further exploration of this inexhaustible resource must be undertaken. Solar energy, wind energy, biomass energy from trees and agricultural wastes, and geothermal energy from within the earth itself are other inexhaustible energy resources that must be explored. The purpose of this series of booklets is to report on explorations of such alternatives.

This booklet considers the major issues involved in the application of wind energy as a significant energy resource in Canada. It outlines the potential of wind energy and how that potential varies with time and geography. Devices for converting the kinetic energy of flowing air into more convenient forms such as mechanical and electrical energy are described, from the traditional massive Dutch windmill to the modern slender wind turbines that are still undergoing research and development. End uses for converted wind energy are considered together with means of satisfying demand patterns using a randomly variable supply. It is hoped that this booklet will provide some insights into the technical and economic characteristics of wind energy and of the systems being developed to harness it as a part of Canada's future energy supply.

Energy Research and Development Program
National Research Council

Conservation and Renewable Energy Branch
Energy, Mines and Resources Canada



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Introduction

INDMILLS have been harnessing the power of the wind since ancient times. But today, in Canada, there are very few windmills at work, and the amount of energy which they provide is a negligible fraction of the enormous quantity we consume.

The staple of our energy diet is, of course, oil. But we cannot rely on oil for very much longer. Only a limited stock of this form of energy has been stored in the Earth. As more and more of it is consumed, what remains becomes less accessible — under the ocean, high in the Arctic — and it is more expensive to produce. The era of abundant, cheap energy which we have been enjoying is coming to an end.

As the price of oil rises, we are being compelled both to control our voracious appetite for energy and to develop a more varied energy diet. The first of these is by far the most important; for it is much easier and cheaper to save energy than to produce it. Nevertheless, we will have to meet our reduced demands for energy in the future by drawing on a broad combination of the sources available to us: nuclear fuels, fossil fuels, hydro power, sunshine, trees, tides, waves and wind. Each of these has its own merits and limitations.

The advantage of wind power is that it is clean, and that we can continue using it indefinitely. But nothing is more fickle than the wind. Its most obvious disadvantage, its random variablity, results in a relatively high price for extracting its power.

In regions where wind speeds tend to be high and where energy costs are high also — in remote Northern communities, for instance, far beyond the reach of the grid of electrical power lines — studies, and some practical experience, show that wind is now an economical power source. But in most parts of the country it would be many times more expensive to obtain power from the wind than from conventional sources; that is why so little use is now made of wind power. In the future, however, as the prices of all forms of energy climb, and as windmill designs are improved, much more energy could be drawn from this clean and renewable source.

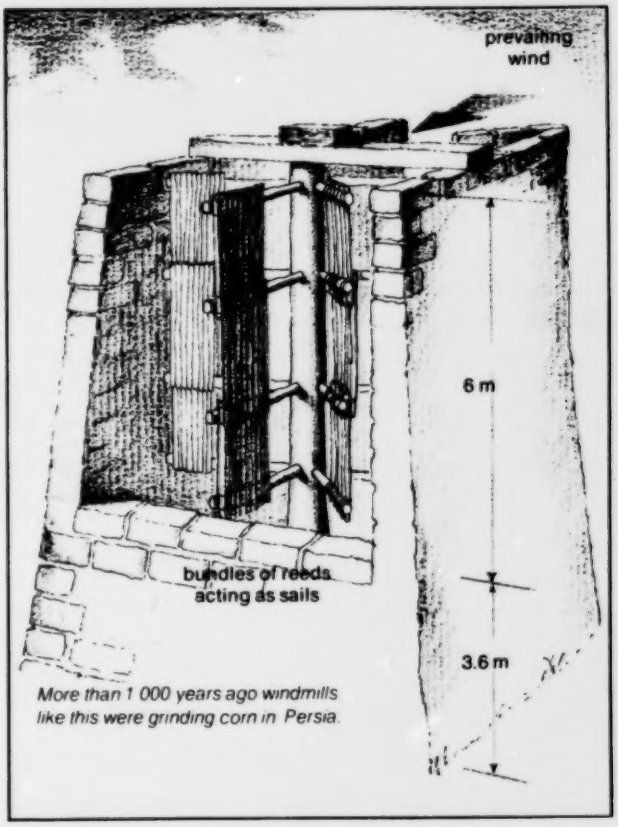
History

We do not know who first thought of using the wind, rather than the muscles of animals or men, to drive machinery, nor where the inventor lived. Both the ancient Chinese and the Egyptians probably had some form of wind power. The earliest reliable records describe the windmills which were used in Persia thirteen centuries ago — and which are very similar to windmills used today in eastern Iran. The Persian windmills consisted of sails, arranged so that when caught by the wind they turned a vertical shaft. Corn was ground by a grindstone turned by the shaft. From the Islamic world this invention was brought to Europe — possibly by returning Crusaders — where it was considerably modified.

The primitive Persian windmills evolved into the whirling-armed giants which Don Quixote charged. Four centuries ago there were more than 20,000 windmills at work in the Netherlands, draining the marshes and lakes of the Rhine river delta to create arable land, grinding grains into flour, running sawmills, crushing seed to make oil. In their day the picturesque Dutch windmills were what oil wells and refineries are today — a prime source of power for a nation's economy.

The use of wind power began to decline with the coming of the steam engine, which unlocked the energy stored in coal and sparked the Industrial Revolution. But windmills never became completely obsolete.

Small windmills were common tools on farms scattered over North America in the early decades of this century. They pumped water for crops, for cattle, and for use in farm houses. Wind-driven electrical generators were first marketed as an accessory to battery-powered radios, and soon became a common sight, producing modest amounts of power for many thousands of isolated homes. But as the electrical distribution grids spread into the countryside, making cheap energy available at the flick of a switch, both these kinds of small windmills fell into disuse.

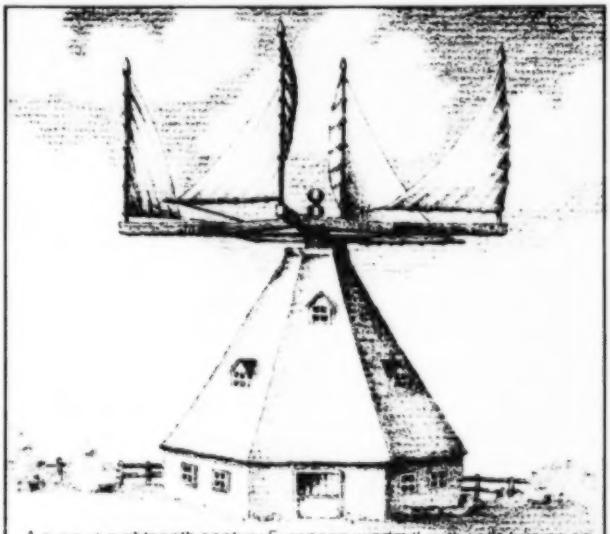


More than 1 000 years ago windmills like this were grinding corn in Persia.

In Denmark, in the 1890's, the first attempt was made to use a large windmill to supply electrical power to a community. This experiment was followed by similar ones in England, France, Russia, Germany and the United States. The most celebrated of all the large windmills was built during World War II on Grampa's Knob, a hilltop in the Green Mountains of Vermont. It was capable of generating

up to 1,250 kilowatts of power*, which was distributed through the power lines of the local utility. While still being tested, one of its huge metal blades snapped off after being weakened by vibration. The machine was never rebuilt; not because it did not work — it did — but because it was just too expensive to maintain. Almost all such experiments with large machines have demonstrated that the cost of electrical energy generated by the wind was too high to be commercially useful.

Is this still true? A number of countries, including Canada, are now building large experimental windmills to find out just how expensive wind energy is likely to be, and, if the results are promising, to find out where and how it might be practical to use it. New ideas are being developed and examined on paper, in the laboratory, and in the field. It seems clear that the ancient technology of wind power is undergoing a revival.



A curious eighteenth century European windmill, with sails turning on a vertical axis to capture the energy of the wind

*A note on energy and power and the units in which they are measured

The precise, technical meanings of 'energy' and 'power' are quite close to their meanings in everyday language. We speak of people having lots of energy, meaning that they can do lots of work, and we speak of people being powerful, meaning that they can do a relatively large amount of work in a relatively short time. Energy, to a scientist, is what makes things go; while power is the rate at which energy is used to make things go. Thus we speak of the energy consumption of an automobile, meaning the amount of fuel converted into work — into transporting passengers from one point to another; and we speak of the power of an automobile, meaning the rate at which it can do work.

There are many possible units in which energy can be measured — gallons of gasoline, BTU's, calories, and more. In the international or metric system, energy is measured in joules. The moving mass of a golf ball which has been dropped from waist height represents about one joule of energy.

The international unit for power, the watt is derived from the joule; a machine with a power of one watt converts one joule of energy in one second. For convenience in describing more rapid rates of energy conversion we also measure power in kilowatts (1 kW = 1,000 watts), and megawatts (1 MW = 1,000,000 watts). The power output of a man bicycling — the rate at which he is converting food energy into mechanical energy — is about 500 watts. The power consumption of a clothes drier — the rate at which it converts electrical energy into heat — is about 5 kilowatts. An automobile moving at top speed develops about 100 kilowatts of power; a jumbo jet, about 200 megawatts. The Pickering nuclear power station near Toronto has a power capacity of 2,000 megawatts.

A kilowatt hour is a convenient unit for measuring electrical energy. One kWh represents the amount of energy which would be stored if the output during one hour of a one kilowatt power generator was accumulated.

The Power of the Winds

Source of Wind Power

What makes the winds blow? What is the motive force that sweeps masses of air across the surface of the globe? The answer is — sunshine.

The quantity of energy which pours down on our planet from the sun is enormous. What happens to it when it arrives? It fuels all forms of life, it powers the cycle of water movement which leads to hydro power, it is captured by plants and very slowly deposited in the form of fossil fuels, and some of it drives the winds.

The materials which cover the surface of the earth, such as rocks, forests, water, all differ in their capacity to absorb heat from sunshine. These differences, combined with a multitude of other variables (such as latitude, time of day, cloud cover) mean that the ground is unevenly heated; its temperature pattern is irregular and changing. The bottom of the 'atmospheric ocean' is heated by the ground, and what happens reproduces, on a global scale, the kind of commotion seen in a pot of boiling water. Basically, the air which is in contact with relatively warm ground is heated and tends to float upwards.

When new air flows in from above chillier regions to replace the warmed air, we call its motion wind. About two per cent of the radiant energy reaching the earth is converted by this process into the mechanical energy of moving air masses.

As anyone who has experienced a gale or hurricane knows, a mass of moving air can act with awesome force. The total magnitude of the power blowing through the skies is extremely large. If it could be converted, without loss, into electricity, it would exceed 10 000 times the combined output of all the generating stations in the world.

But in practice, only a small fraction of the raw energy in the winds can be captured and put to use. The behavior of moving air, the laws of physics and economics all limit the wind's potential as an energy resource.

Distribution of Wind Power

One of the major limitations on the amount of raw wind power which can be harnessed is imposed by its inconvenient distribution.

All the energy blowing in the earth s winds comes from the sun

We know from everyday experience that some places are windier than others, and that the faster the winds blow over a spot on the earth's surface, the more power there is to be captured. However, the relationship is not a simple one. It is described mathematically by the 'cube law', which states that the power of a wind is proportional to the cube of its speed — that is, to the number representing speed multiplied by itself three times. The cube of two is eight ($2 \times 2 \times 2 = 8$), and so a doubling of wind speed means an eight-fold increase in power, and a halving of speed means an eight-fold reduction in power. Thus most of the power in the winds is carried by the faster winds.

Consider a moderate 25 km/h breeze, which can set leaves rustling and raise dust or scraps of paper. A stream of air blowing at this speed through a window frame of one square metre in area has a raw power of about 200 watts. If its speed drops slightly, to 20 km/h, little difference will be seen — leaves and twigs will still be in constant motion

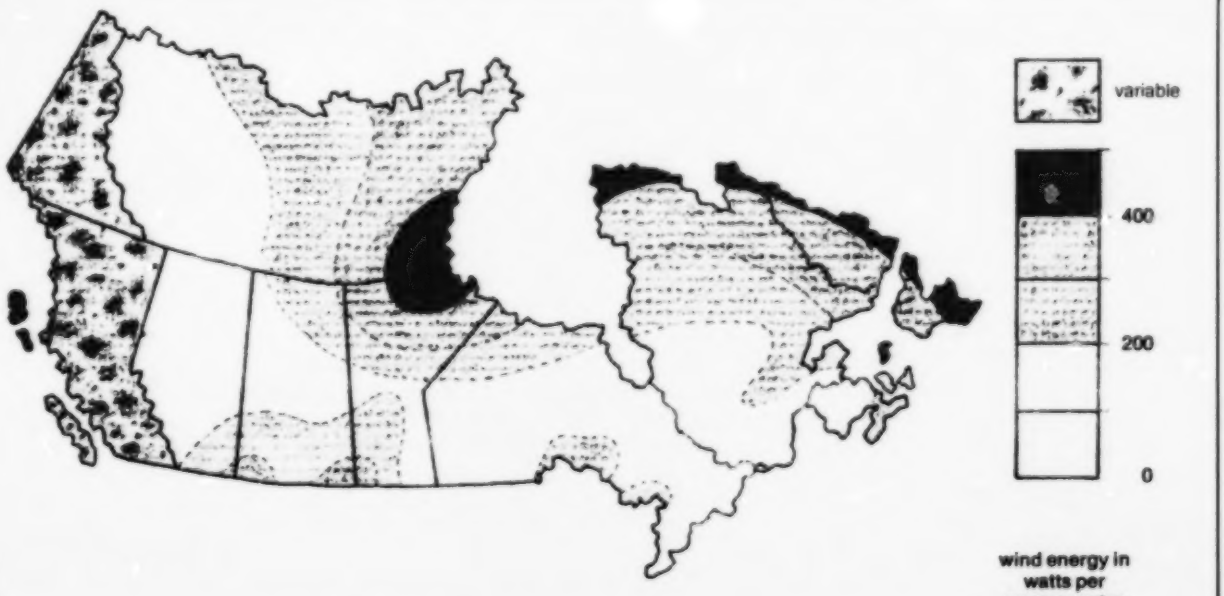
— but the power of the breeze will have dropped sharply to 100 watts, half its former value.

In practical terms the relationship between speed and power means that when the wind is calm, which can happen at the windiest of sites, there is no raw power at all to be captured. When the wind does blow, its speed fluctuates unpredictably from moment to moment, and its power fluctuates even more widely. A rough measure of the power available at any particular site is provided by the average of all the wind speeds observed over the course of a year, including zero readings taken during calm spells. Where annual average speeds exceed 20 km/h, the winds carry useful amounts of power. Where average speeds fall much below this value, the winds are too weak to warrant harvesting.

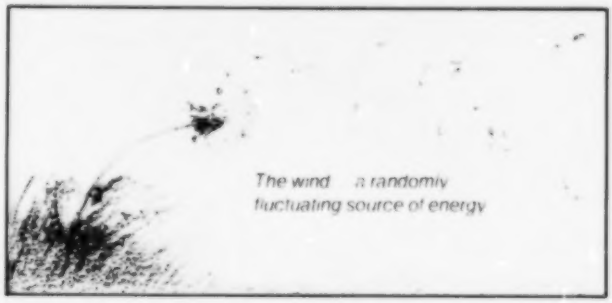
Where are the windy regions in Canada? How is the power of the moving atmosphere distributed across the country? The map on this page gives some general answers. What is plotted is density of wind power, expressed as the annual average rate at which energy flows through a vertical area of one square metre placed 30 metres above the ground. That may sound complex, but reading the map is easy.

In three regions — along the exposed coasts of the East, the Gulf of St. Lawrence and Labrador; in the North, around Hudson's Bay; and in the southwestern prairies — the wind energy flows are quite strong. In these regions a windmill mounted on a 30 metre high tower would intercept lots of raw power — 300 or more watts on the average for every square metre of area swept by its spinning blades. There are also high energy regions in the mountains of British Columbia, but few data have been gathered here, and the details of very windy and very sheltered spots occurring beside each other are too fine for plotting on a map of this scale.

These windy areas tend to be far from the population centers where most people live, and where most energy is used. In the densely populated southern parts of Canada, wind energy flows are, on the whole, relatively weak.



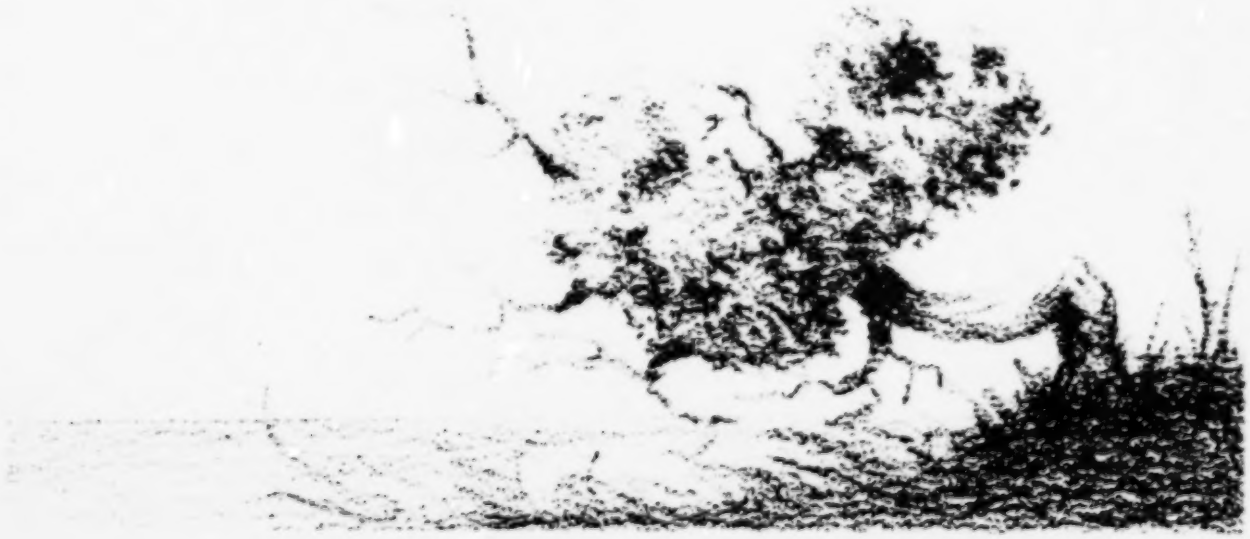
The windiest parts of Canada are the darkest parts of this map.



The wind ... a randomly fluctuating source of energy

There may, nevertheless, be many unidentified windy sites in the low energy regions. For local features of the terrain — an isolated hill, for example — can greatly change the wind speed, and following the cube law, the wind power. If the hill is of the ideal shape, with smooth but not steep slopes, it will act like an airplane's wing to accelerate the air flowing over its summit. The power available on top of such a hill would be strikingly greater than that available in its immediate surroundings. Because of such effects, because wind power can vary dramatically from place to place, the map can only give a very broad picture of its distribution. The map, in fact, is based on average wind speeds recorded over the course of a year at weather stations scattered across the country, and none of these stations was located with the intention of identifying good sites for capturing wind power.

Although the total power of the winds blowing over Canada is enormous, it is available in strength mainly in regions where energy is not needed, and it tends to be weak where energy is needed. The wind, to sum up, is an intermittent, randomly fluctuating and inconveniently distributed source of energy. These limitations in how wind power occurs in nature make designing wind-powered machines (the subject of the next section) an interesting challenge.



Wind Powered Machinery

Systems and Efficiency

Energy is defined in high school texts as the capacity to do work. But even if energy blows over your roof at a worthwhile rate, it cannot do useful work, such as pump water or light electric bulbs, in its raw form. It must first be captured and then converted.

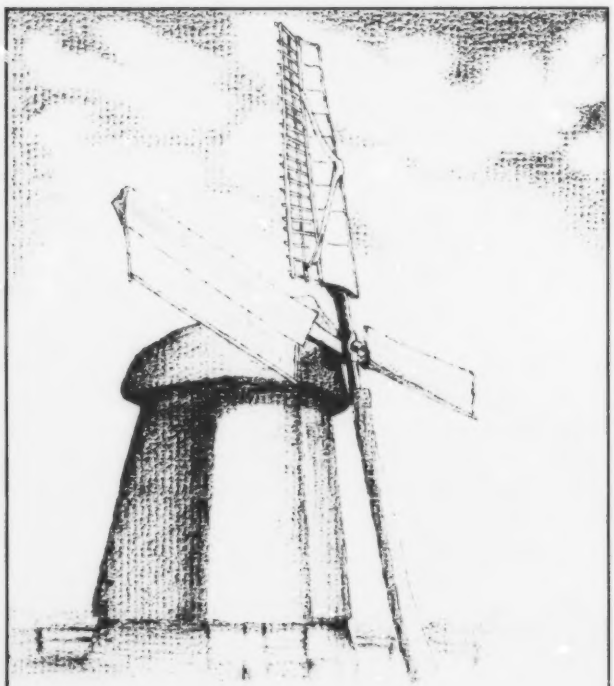
A wind turbine spinning on top of a metal tower, an electrical generator driven by the turbine shaft, batteries to store power for use during windless days — these are the kinds of hardware which are connected in what an engineer would call a 'wind energy conversion system'.

As the name implies, each of the components in such a system converts energy from one form to another. The turbine takes energy from the moving air masses and converts it into the form used by most machinery — a turning shaft; the generator converts this mechanical energy into electrical energy; the batteries convert electrical energy into the electrochemical form in which it can be stored; the lightbulbs run by the system convert electrical into radiant energy — which, curiously enough, was the original form in which energy began this chain of conversions: the sunshine which sets the winds in motion was also radiant energy.

If all the energy captured from the wind and passed from one converter to another could be made available to do useful work, we would say that the system was 100% efficient. But the efficiency of most energy converters is much lower than 100%, for in changing the form of energy they usually lose some of it. A wind turbine for instance, can never capture more than about 50% of the raw energy of the moving air it intercepts, and the efficiency of practical wind turbines is considered high if it reaches 40%.

There are many possible chains of conversions in wind energy systems. There are water pumping windmills, for instance, in which wind energy becomes the up and down mechanical motion of a pump, and wind furnaces, in which it is converted into heat; but the most common form in which wind energy is used is that of electricity.

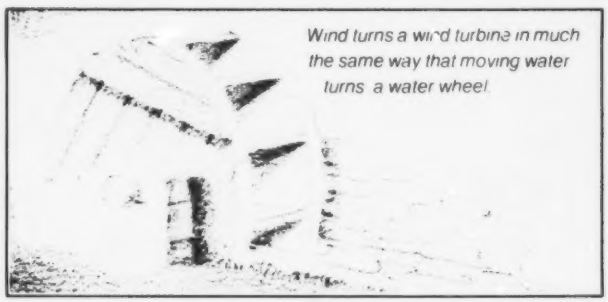
There are many possible sizes of wind energy systems. There are small systems, producing up to 10 kilowatts of power, such as the battery charging windmills used at some unmanned weather stations in the Arctic, or the commercially available systems for supplying electric power to a home. There are systems of intermediate size,



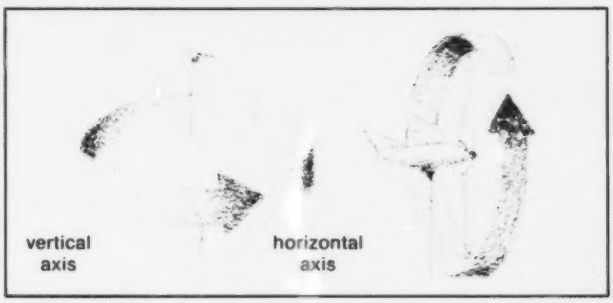
A Dutch windmill at rest

10-100 kilowatts, which could be used in small remote communities; and there are large systems, from 100 kilowatts to several megawatts of power, such as the wind powered generating station proposed for use by Hydro-Québec.

No matter what its chain of energy-converting steps, or its size, no wind system can make available in useful form more than a fraction of the raw power of the wind with which it is contact. The most efficient wind systems known produce, on the average, about 45% of the power in the winds they intercept.



Wind turns a wind turbine in much the same way that moving water turns a water wheel.



Wind Turbines

The heart of any wind energy converting system is its turbine, the part that turns in the wind. A wind turbine is driven by moving air. It works by slowing down the stream of air which it intercepts. The power robbed from the wind's forward motion is converted into rotation of the turbine. Essentially, a wind turbine works like a water wheel, driven around by moving water. But air being hundreds of times less dense than water, wind turbines are much larger than water turbines of the same power output. As the area of the wind stream passing through a turbine's spinning blades is increased, so too is the power extracted.

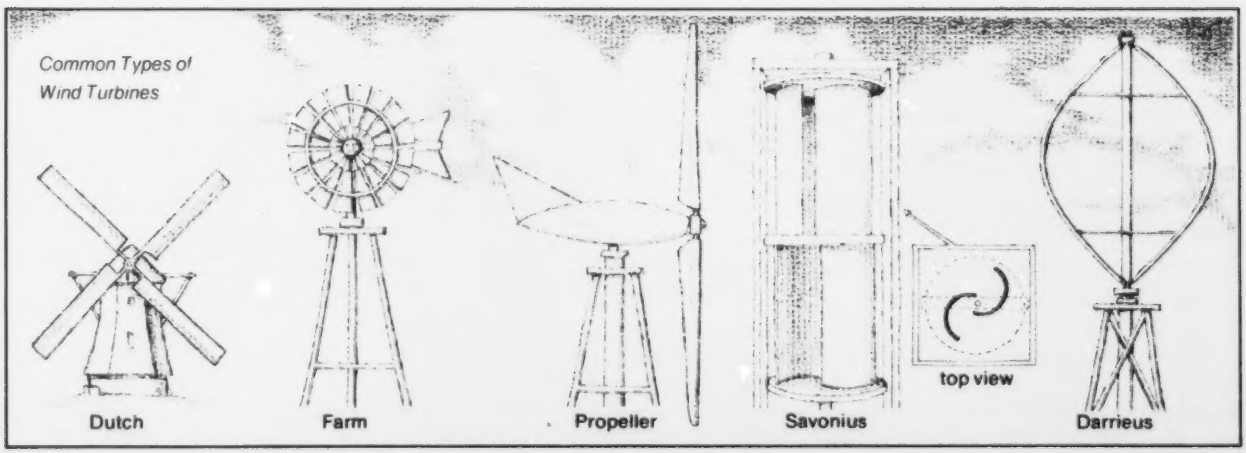
Wind turbines are put to work in difficult conditions, especially in Canada. They are exposed to the forces of nature, to ice, corrosive salt spray, dust, to the stresses and vibrations imposed by strong and occasional turbulent, swirling winds — and they must keep rotating. Designing a durable, efficient wind turbine is no easy task.

There are two main kinds of wind turbine: those which turn around a horizontal axis, as does a Ferris wheel, and those which turn on a vertical axis, as does a Merry-Go-Round.

Horizontal Axis Wind Turbines

The ponderous Dutch windmills with four wooden sails, and the water pumping farm windmills, each with a fan of many metal blades, are probably the most familiar wind turbines. Both kinds turn on a horizontal axis, as do the rapidly rotating propeller-like blades of modern wind machines.

Both the Dutch and the farm machines turned fairly slowly. Though they did not extract very much of the total energy of the wind, they could start turning in winds of quite low speeds, generating useful amounts of mechanical power in the form of a turning force or torque, and they were



thus well suited for mechanical work such as grinding and pumping.

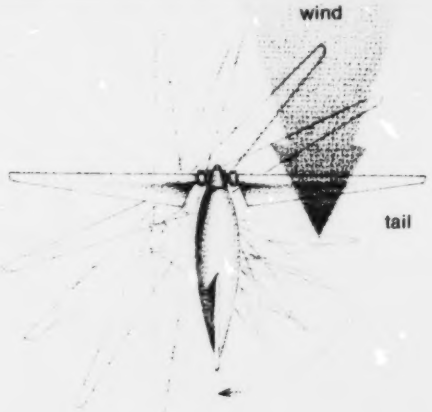
Modern propeller wind turbines have a few, light, streamlined blades. They are designed to rotate rapidly — the outer tips of the blades can travel five or six times faster than the wind driving them around. Such a design is intended to be used to drive electrical generators — most of which run at high speeds of rotation — and used in electrical systems, these turbines are quite efficient.

One requirement complicating all wind turbine design is the prevention of over-speeding; for winds can blow at speeds and strengths that exceed the power handling capability of the turbine. If excess power is not spilled, turbines and towers can be toppled, or generators 'burned' out. There are as many methods of controlling the speed of a turbine as there are turbine designers and manufacturers. Some of the Dutch windmills, for example, had shutters in their sails which could be opened, rather like venetian blinds, to let the high winds pass through. To protect his water pumper during a storm, a farmer might have to 'furl' his windmill. This meant swinging the turbine around on top of its tower so that the blades were sideways to, and hence partly protected from, the wind. Modern windmills are frequently designed with blades that can be 'feathered' — that is, the angle of the blades can be adjusted so that less surface and more edge is presented to the wind as its speed increases.

Horizontal axis wind turbines have a special design requirement: they must face the oncoming wind if they are to capture its power. Thus they need an orienting mechanism to swing them around as the wind shifts direction. To do this, farm windmills had a tail or vane which, like a flag, always pointed downwind, and hence turned the blades to face upwind. Other turbines have other orienting devices, but in all, the necessity for the blades to swing around as the wind changes direction, as well as turning in the wind, complicates the task of bringing its power down to the ground in useful form.

Vertical Axis Wind Turbines

The Persian windmills of thirteen centuries ago turned on vertical axes, a venerable arrangement whose use has been revived in some modern wind turbine designs. What makes it attractive is its mechanical simplicity: unlike



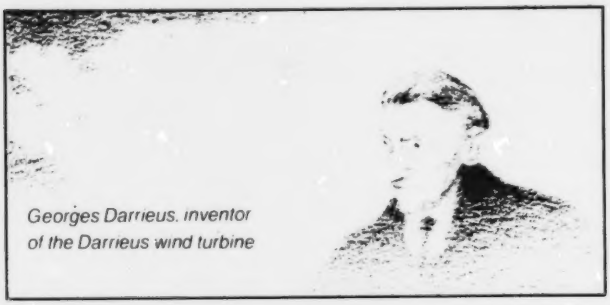
By means of its tail, this horizontal axis wind turbine is oriented to face in the direction from which the wind blows.

horizontal axis machines, vertical axis turbines do not need to be turned as the wind changes direction.

The simplest of this type is the Savonius turbine, named after the Finnish inventor who patented it in 1931. It can be made by splitting an empty oil drum lengthwise, and then welding the two half cylinders so that they turn around a central, vertical axis. When seen from above, the Savonius turbine consists of two air scoops forming an S shape. Such a device does not rotate very rapidly, nor is it very efficient. But it is particularly cheap and easy to build, and can be used for pumping water, ventilating buildings, and although inefficiently, generating electricity.

The Darrieus turbine is named after its French inventor, who also patented his design in 1931, but, unlike Savonius, did not have the opportunity to further develop it. It was forgotten — until the late 1960's, when it was reinvented by two aeronautical engineers at the National Research Council in Ottawa, Raj Rangi and Peter South. Since then it has been developed by pioneering work in Canada.

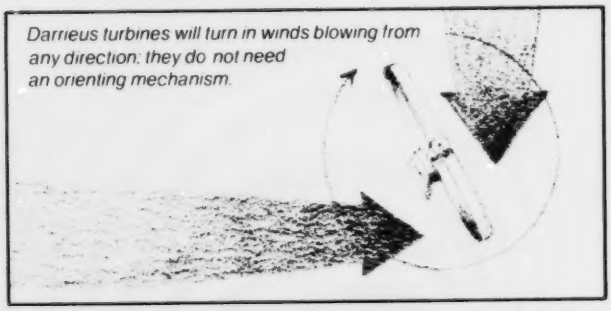
A Darrieus wind turbine looks somewhat like a large kitchen eggbeater. Each of its blades is attached at both ends to a central shaft, and follows a curve close to that of a semi-circle. In cross section each of the blades is shaped like an airplane's wing; it is the lifting force developed by air



Georges Darrieus, inventor of the Darrieus wind turbine

flowing around them that spins the turbine and generates power.

Darrieus turbines have efficiencies almost as high as the best horizontal axis machines, and both kinds can be used for the same tasks. But the Darrieus turbines offer some relative advantages. Being omni-directional, for instance, they do not need the complications of orienting mechanism. Power can be "taken off" at the base of the shaft; in horizontal axis machines the heavy equipment which this requires — gears, generators and so on — has to be placed



Darrieus turbines will turn in winds blowing from any direction; they do not need an orienting mechanism.

on top of an expensive tower. Controls are fairly simple on Darrieus turbines, because the blades tend to automatically regulate their speed of rotation; when the wind speed exceeds a certain value the blades no longer generate lifting force, but begin to stall, as does an airplane climbing at too steep an angle. For such reasons, Darrieus turbines promise to be simpler to design and cheaper to construct than other kinds.

They do have some relative disadvantages. When connected to a load, that is when not free to turn unless they also turn a generator, they do not start by themselves even if the winds are strong. Their blades have to be set in motion by some power source other than the wind. This can be arranged quite simply by drawing electrical power from the grid, so that the generator momentarily becomes a motor and starts the turbine turning. Once started, the wind driven generator feeds power into the grid. Though eggbeater windmills are still at an early stage in their development, it is clear that their ideal application is in generating electricity to be transmitted through power company lines.

Towers

The lowest layers of the air sweeping over the earth are both slowed down and made turbulent by friction with the ground. This is why windmills are located away from any obstructions such as buildings or trees and placed up on towers; for this is the best way to intercept the fast and smooth flowing air when the ideal support structure for a windmill, a mountain top, is not available. For small horizontal axis turbines, the optimum height of tower is usually between 30 and 45 metres, and its cost is a significant fraction of that of the whole system.

Mounting a windmill on a roof is not a good idea, for few building structures have been designed to withstand the kinds of vibration and stress involved in supporting a spinning wind turbine. This, and the fact that the wind, like traffic, tends to get snarled in flowing around a city — it becomes turbulent, and its energy is difficult to extract — means that there are rarely good locations for windmills in cities.

Generators and other Energy Converters

All wind systems first capture power in mechanical form by means of a turbine, but from this common point many possible paths branch off, each representing a different series of conversions of the original mechanical power. It is possible to get heat from a windmill, for instance, by using the turbine's turning power to drive paddles which agitate a tank of water, thus producing heat by friction. It is also possible to produce heat by having the turbine drive a generator, thus converting mechanical to electrical power, and supplying this power to heating elements immersed in water, thus converting electrical energy into heat.

On many such paths down which wind energy flows, there are generators, converting energy into one of its most useful forms — electricity. Generators work on the

principle that the relative rotation of two magnets produces an electrical current. This current can be of two kinds, depending on the arrangement of magnets: alternating, or direct.

The power company delivers electricity to your home in the form of an alternating current (AC) — one which reverses its direction many times every second. Electrical generators for producing alternating currents are called alternators. Since they are in common use they are relatively cheap and durable. A major disadvantge of using an alternator in a wind system is that the AC power it produces cannot be conveniently stored. Moreover, the alternator must rotate at a fixed speed if it is to produce a current that alternates, as does the power company's, at a constant frequency of 60 cycles per second. This means that the windmill which drives the alternator must turn at a constant speed, which in turn means either a somewhat inefficient turbine, or a costly gearing mechanism.

The electricity used in an automobile is in direct current (DC) form — it always flows in the same direction. Generators for producing DC power can operate at varying speeds but are generally more expensive and less efficient than alternators. However, they have the advantage of producing power which can easily, though expensively, be stored in batteries. Some household appliances, such as lights, heating elements and hand power tools, can run on DC power, but not all.

Devices for changing electric currents from one of these forms to the other exist — rectifiers change AC to DC, and inverters change DC to AC. Unfortunately, such devices are expensive, and the energy which is lost in passing through them decreases the overall efficiency of a wind system.

In general, the more energy conversions there are in any path from raw energy supply to useful work output, the greater the cost and inefficiency of the whole system.

Storage

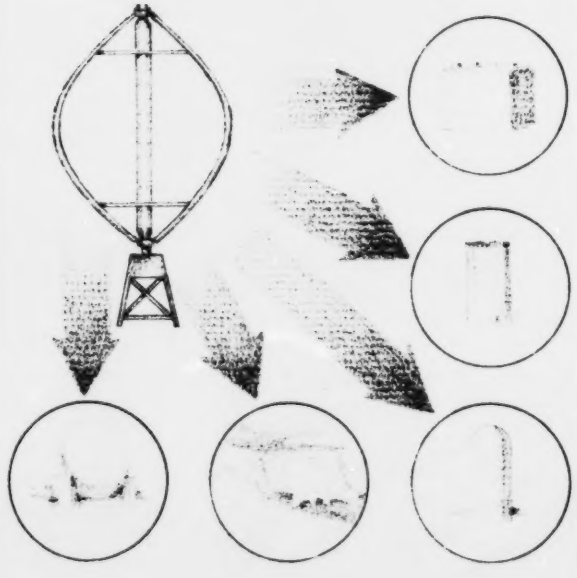
The wind is not always blowing when its energy is needed. Some way of storing energy when it is available, for use when the winds are calm, adds greatly to the convenience of wind energy conversion systems — and to their complexity and cost.

In small wind electric systems storage is provided by a bank of lead-acid batteries. These batteries are similar to an automobile's, but have thicker lead plates, and a longer life span: the chemical process by which energy is stored — the solution and deposition of lead — must be able to continue for many cycles of charging and discharging in a wind system.

There are a number of other possible ways to store wind energy:

Heat

The energy produced in a small wind system can be converted into heat, and, when not needed, stored in a well insulated tank of water. In fact such systems are probably the most practical and economically sensible way to use wind power in a household today.



Ways of storing energy from the wind

Compressed Air

Air pumps, driven by windmills, provide another way of storing wind energy — in the form of compressed air. Power tools could be driven from tanks of compressed air in small systems. On a larger scale, wind energy stored by compressing air in abandoned mines or natural underground caverns could be converted into electricity by means of air-powered generators.

Pumped Storage

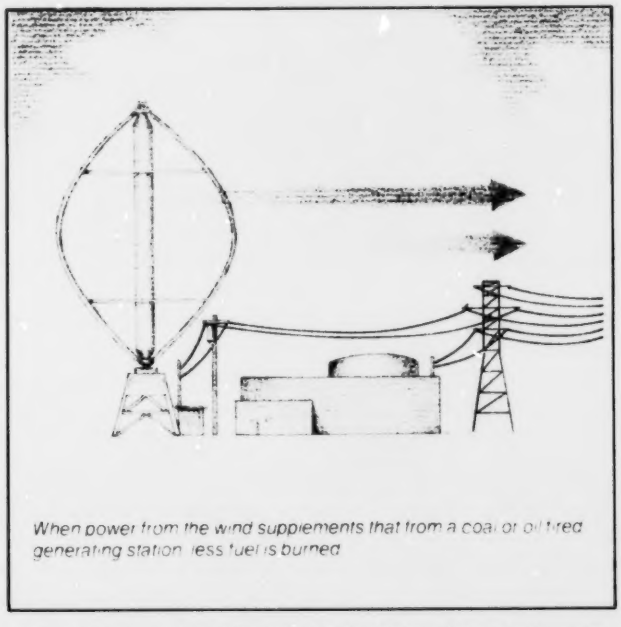
Wind-powered pumps could be used to lift water into a reservoir above a hydro-electric generating plant. The power captured during windy periods is thus stored, and can be retrieved when needed simply by allowing water to fall through the plant's turbines, producing electricity

Hydrogen

In the 1880's, Poul La Cour, the Danish wind-energy experimenter, illuminated the school in which he taught by burning a gas produced from water with wind power. The gas was hydrogen, which in combination with oxygen forms water. If energy from the wind is converted into electricity, it can be used to separate water into its constituents. The hydrogen produced could be stored, moved around the country, and used as a fuel in much the same way as we now use natural gas.

By far the simplest and cheapest solution to the problem of energy storage is to avoid it: that is to use wind power when and where it is available, for tasks that do not depend on a constant flow of power from a single source. This is what happens in a wind system for pumping water on a farm. Water is raised only when the wind is blowing. There are no storage or back-up units to raise water when the wind is calm.

In order to ensure that a small wind electric system can provide power no matter what the wind conditions might be, a bank of storage batteries is usually required, as well as some back-up power source, such as a diesel-powered generator, for use when the batteries have been drained after a number of windless days. To avoid all this, a device known as a synchronous inverter can be used. What it does is synchronize the alternating current produced by the wind so that it is identical in all respects with that in the power grid. When power is produced from the wind, but is not needed, it can be 'stored' by being fed into the power company lines. Provided specific safety equipment is installed by the windmill owner, utilities in a number of provinces will buy surplus power — though at rates lower than those at which power is sold. When power is needed, but is not available from the wind, it is bought from the mains of the power company By plugging a wind system into the power grid, the need for storage and back-up is eliminated.



When power from the wind supplements that from a coal or oil fired generating station less fuel is burned

This strategy works for larger systems too Many of the wind power experiments now under way in Canada are examinations of intermediate-sized wind generators feeding power directly into the transmission network. By avoiding storage, such systems become particularly practical and economical. When the winds are not blowing, the power in the grid comes entirely from some conventional source, such as an oil-powered generating station. When the winds are blowing, the power in the grid comes from both wind and fuel. Since less fuel is burned in supplying the demands for power from the grid, these kinds of mixed systems are known as 'fuel savers'.

Costs

Many people think of wind energy as being free for the taking. The winds are certainly free, but taking energy from them is costly.

Many individuals dream of putting up a small wind system and becoming self-sufficient in energy. It can and has been done — but only by those who eliminate extravagant needs for energy from their lives and develop practical skills as electricians and windmill technicians; or by those who can afford the expensive and extensive hardware needed to extract from the winds the amounts of power used in a typical North American home. The most cost effective way of using wind power, the way in which the units of energy delivered are least expensive, is generally not with small systems meeting an individual family's needs, but with larger systems, serving communities.

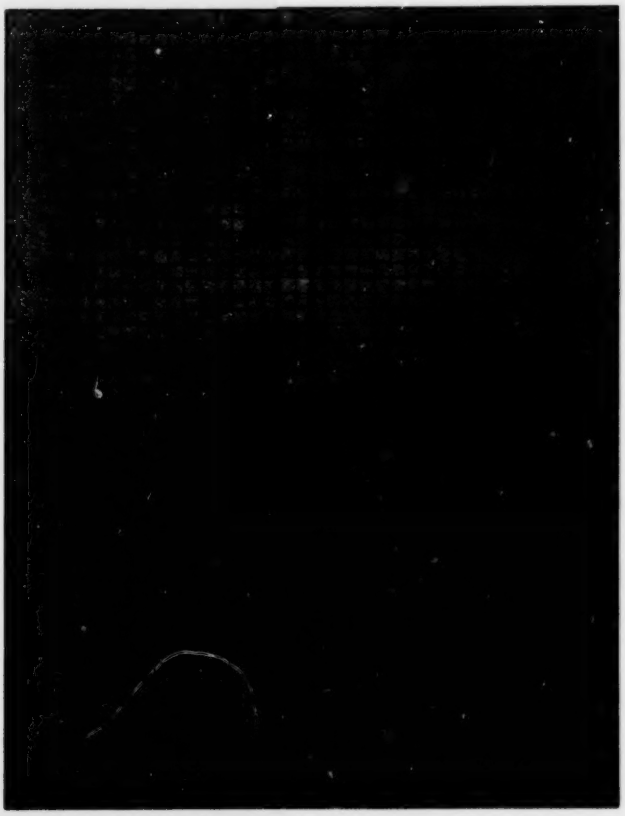
Just how much does wind energy cost? How does its cost compare with that of energy from other sources? The answers depend on variables and guesses — on the location and size of a windmill, and the amount of energy it actually produces from the random winds; on estimates about the future availability and cost of energy from other sources.

Consider this concrete example. You would like to buy a small wind powered electric system for a cottage. You do not require very much power, just enough to run some light bulbs, a water pump, and the odd appliance. Your calculations show that a wind power generator capable of providing 1,000 watts would suffice.

Next you study the winds at your cottage. To estimate with reasonable accuracy the energy you are likely to gather, the wind patterns need to be recorded daily over the course of a year. The data from the nearest weather station can only give a very rough guide to what you can expect.

The pattern of wind speeds which you observe is that the faster, energy containing winds blow, on the average, about two days a week. Slower winds, carrying much less energy, are more common. For periods as long as a week, usually in the summer, the winds hardly blow at all.

With this information, and the operating characteristics of the system you have chosen which are listed in the manufacturer's catalogue, you can predict how much energy you will gather.



Whenever the wind speed is less than 10 km/h, the blades of your turbine lie idle. If the wind picks up, exceeding this 'cut-in-speed', the blades will start turning and some power will be generated. Not until the wind speed reaches 35 km/h is your generator putting out its full potential of 1,000 watts. Though considerably more power is blowing in winds that travel faster than 35 km/h, the system cannot significantly increase its output: it continues to produce 1,000 watts of power until the wind speed reaches 60 km/h, at which point the vibrations and stresses become so hazardous that the system is shut down, and energy production ceases.

What all this means is that the average power which you can expect your system to deliver is much less than 1,000 watts; the power actually gathered by a wind system is about one quarter of its rated output, or, in this example, 250 watts. Over the course of all the hours in a year then, you may expect to gather 2,190 kWh of energy.

The price of electricity varies from province to province, but assuming a typical current figure of 5 cents per kWh, the energy gathered from the wind during a year would cost about $100 if your cottage was connected to the power lines.

How much would it cost to get this energy from the wind? Small wind generating systems cost about $2 per watt of rated output, a rule of thumb figure which does not include the cost of batteries and a tower — these can easily double the price for equipment. Your investment therefore would be a minimum of $2,000. Assuming a 15% rate of return on this investment, and an equipment lifetime of 20 years, the energy that you might get would cost $300 a year.

Wind energy, in this example, is at least three times more expensive than electrical energy. And in general such calculations demonstrate that a dollar invested in thermal power plants, nuclear power stations or hydroelectric generating stations produces three or four times more power than a dollar invested in a wind system.

At a reasonably windy site this wind system delivers, on the average, about one quarter of its rated power of one kilowatt

But a number of important considerations are ignored in this generalization.

There is the question of location. If the cottage in our example was at any distance from the power grid, stringing power lines to deliver electricity to it would be prohibitively expensive — which is to say that wind energy could make sense. In remote locations, energy from conventional sources costs much more than it does in the populated areas served by the power grids and pipelines. If fuel has to be flown into an Arctic community, for example, to power a diesel generator, the cost of the electricity produced is very high. In such circumstances using the wind as part of a mixed fuel saving system is economically competitive right now.

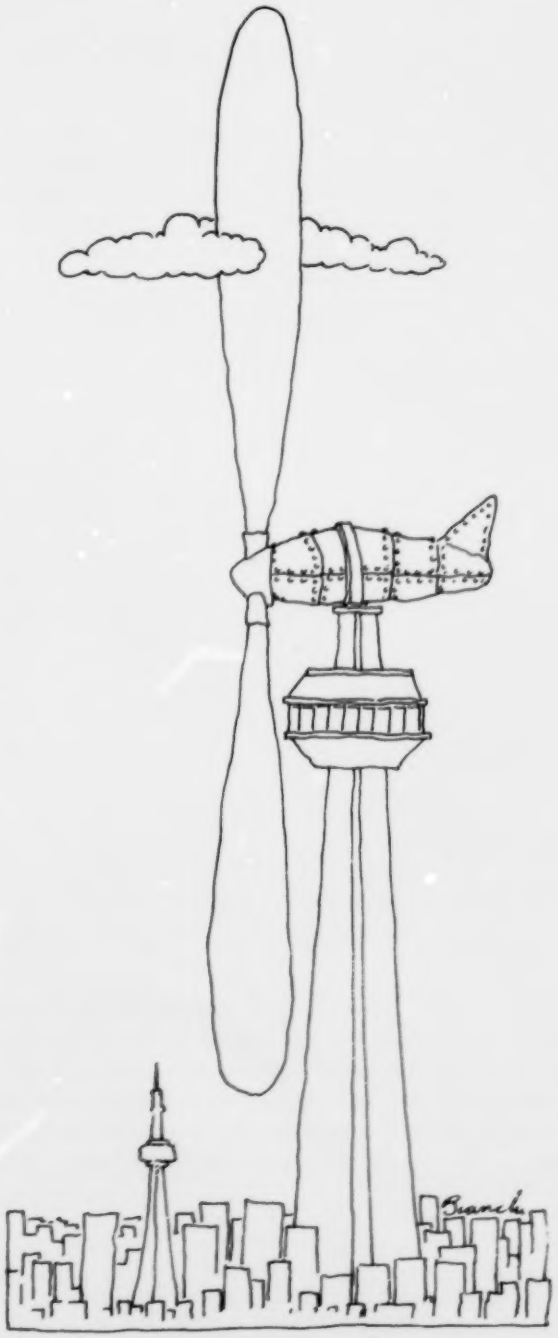
Windiness is also a consideration. The same windmill will produce much more power in a windy spot than in a sheltered one. The windier the site, the less the cost of the energy gathered there.

There is also the question of size. Small wind systems could be economical sources of power for pumps and other tools on a farm, for households which minimize their energy use or which are in relatively remote and windy spots, and for such applications as charging batteries at isolated weather and communications stations.

As the size of wind machines increases, the cost of the energy produced decreases, and the possibilities of economical application broaden considerably. Design studies show that wind machines whose power is rated in millions of watts, and whose height exceeds that of a 30 storey building, are not only feasible but also minimize the cost of wind power. Why? Because of what are called economies of scale — it is often cheaper to build and operate a few large scale machines than many small ones. Large windmills feeding electric power directly into the grids are likely to tap far more wind power in the future than will small systems.

There are considerations of value which are not reflected in the price tag for wind energy. Energy obtained from the wind is clean; energy obtained from most conventional sources is not. Nuclear plants currently produce electricity at cheaper rates than do windmills, but they also produce radioactive wastes. Coal burning power stations produce electricity at cheaper prices too, but they pollute the air with carbon and sulphur dioxides, leading to an increase in the global temperature, acid rain, and, eventually, a hazard to life. Even at somewhat higher than current prices, wind energy could be attractive if its cleanliness is valued.

Finally, it is important to realize that a comparison of energy prices today is not valid for tomorrow. All forms of energy drawn from non-renewable sources are ultimately going to become extremely expensive, but modern technology for drawing power from renewable sources such as the wind is still young, and researchers now at work could well develop ideas and equipment which will lower the cost of wind power.



Research

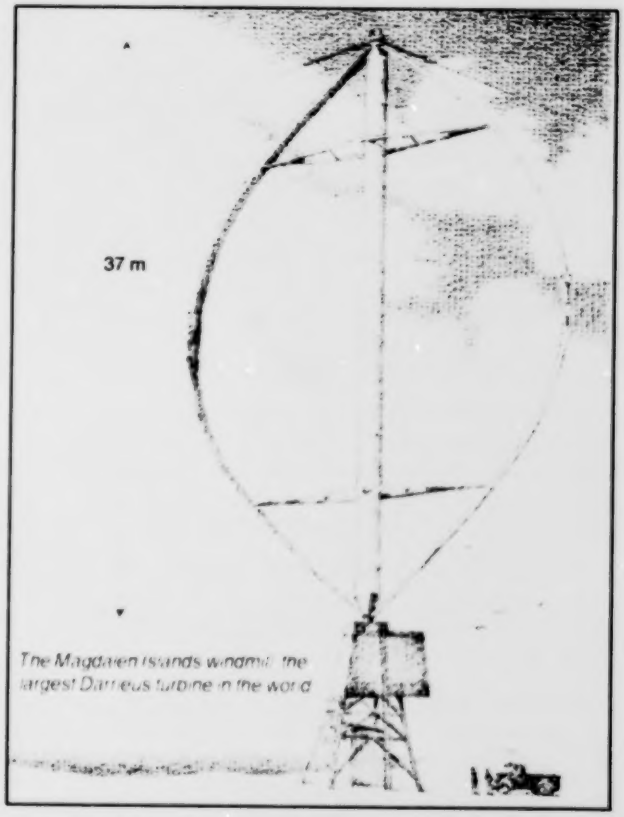
The amount of power that can and will be taken from the winds blowing over Canada depends, finally, on economics. The question that wind power researchers are tackling, both here and abroad, is not "Can we make it work?", but rather "Can we bring the costs down?".

The scope for ingenuity in the design, construction and application of cheaper wind systems is considerable. Can durable and low cost wind turbine blades be made from some new combination of materials? What can be learned about the behaviour of turbines by running them in the precisely controlled conditions of a wind tunnel? In what regions should more data be gathered on the wind regime, so that a more accurate estimate may be made of the potential experience with running windmills out in the field and by simulating complex combinations of wind and other power sources on computers?

These, and a host of other questions, are being asked by researchers in federal and provincial government agencies, in university and company laboratories, and by individual experimenters. The spectrum of research in Canada is so broad that only a part of it, that in which the federal government is most involved, can be sketched here. The selection of addresses and readings that follow should help guide the interested reader to further coverage.

Under the federal government's energy research and development program the Department of Energy, Mines and Resources is responsible for developing policies for the country, and the National Research Council is responsbile for coordinating research on renewable energy sources, including the wind. Almost $2 million was spent on wind energy research in 1980 to support work in government, university and company laboratories, field trials with power companies, and more.

Much of this research centers on Canada's most notable contribution to the field of wind power — the Darrieus turbine. The application being most intensively examined is that of fuel-saving with intermediate to large machines. By supplementing another source of energy when the winds blow, by feeding power directly into a grid and thus avoiding expensive storage, Darrieus turbines could supply significant quantities of energy from the wind at a reasonable cost.



The Magdalen Islands windmill, the largest Darrieus turbine in the world

The world's largest Darrieus turbine was erected on the low-lying Magdalen Islands in the Gulf of St. Lawrence in May 1977. This experimental machine drives a generator, which in high winds — not at all rare on the Magdalen Islands, one of the windiest corners of Canada — can feed a maximum of 230 kilowatts of power into the local grid. This is not very much — in fact the 13,000 or so islanders use more than 100 times that amount of power at times of peak consumption. To meet most of their needs, the local grid carries power generated on the island by burning diesel fuel, shipped at considerable expense from the mainland. Some of this fuel can be saved when the winds blow.

In July, 1978 the turbine collapsed. It had been left overnight, disconnected from its generator and unbraked; it started to turn by itself, accelerating to speeds far greater than those which it had been designed to withstand; the flaps on its blades which were supposed to brake it in just such an emergency failed to work; it ran out of control, shook its supporting wires loose and crashed to the ground.

What caused the accident? It was not due to any basic flaw in the design of the Darrieus turbine, a team of investigators decided, but to inexperience. Wind power technology is still evolving; much remains to be learned. The Magdalen Islands experiment now continues, with a new rotor which was installed in October, 1979.

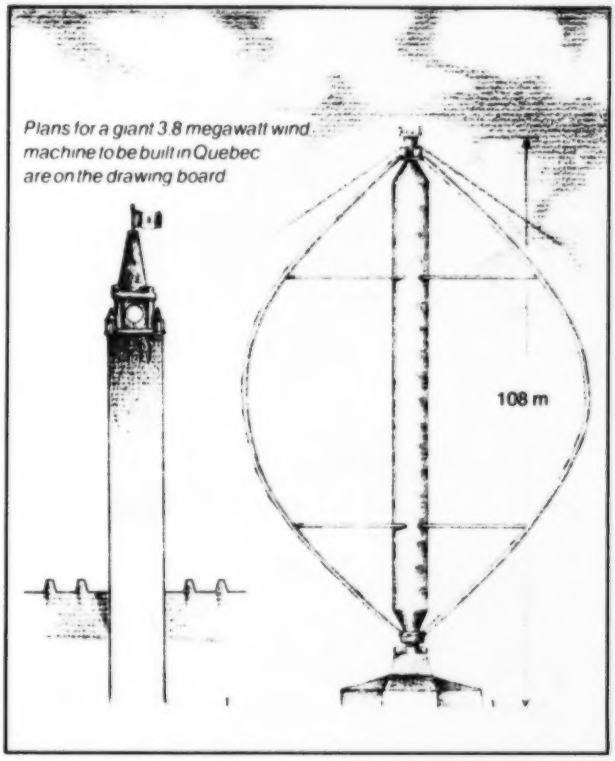
Smaller systems, similar in design to the large prototype on the Magdalen Islands, but with only 50 kilowatts or a quarter of its potential power, are also being tested in the field. They too are being used as fuel savers. In a number of provinces they feed power into grids.

In Ontario, experiments are under way with a wind turbine directly connected to a diesel generator to form a system which could reliably provide power, when needed, in small, isolated communities not served by a grid.

On the wind-swept north-western tip of Prince Edward Island a laboratory for the real life evaluation of wind energy conversion systems has been established. Here at the Atlantic Wind Test Site inventors can have new wind turbine concepts tested, and manufacturers can obtain objective data on the performance of their machines.

Most wind power researchers agree that the largest contribution of power is going to come from big machines. Windmills capable of generating over one megawatt of power are on the drawing boards, or under construction, in Germany, Great Britain and the USA. One machine of this size is now running in Denmark. In Canada plans for a much more powerful version of the Magdalen Islands' machine have been drawn up — a 3.8 megawatt giant which is being built in Quebec and whose estimated $18 million cost is being shared by Hydro-Québec and the National Research Council.

Just how much power could such machines gather from the winds which blow over Canada? Until practical experience with the large scale generation of electricity from the wind is acquired, the answer to the question will remain in the realm of informed speculation. But calculations show that if hundreds of such large machines were



Plans for a giant 3.8 megawatt wind machine to be built in Quebec are on the drawing board

erected at points where winds are reasonably strong and where existing power transmission lines are reasonably close, they would provide up to 5% of all the electrical power now used in Canada. They would provide this power from a renewable and non-polluting source, and they would provide it despite the random variations of the wind.

Sources of Information

Some Research Organizations

ALBERTA RESEARCH COUNCIL
Solar and Wind Energy Research Program
11315-87th Avenue
Edmonton, Alberta T6G 2C2

ATLANTIC WIND TEST SITE
P.O. Box 189
Tignish, P.E.I. C0B 2B0
A laboratory at which the real life performance of wind systems can be measured.

BRACE RESEARCH INSTITUTE
Macdonald College
McGill University
St. Anne de Bellevue, Quebec H0A 1C0
Developing cheap, simply constructed windmills.
Publishes construction plans, lists of commercially available equipment.

BRISTOL AEROSPACE LIMITED
P.O. Box 874
Winnipeg, Manitoba R3C 2S4
Developing rugged Darrieus turbines and generators.

CANADIAN ENERGY CONVERSION INDUSTRIES
2779 Lake City Way
Burnaby, B.C. V5A 2Z8
Developing Darrieus and other wind turbines.

CROWFIELD ASSOCIATES LIMITED
Crapaud RR 1
Charlottetown, P.E.I. C0A 1J0
Developing a 'heat churn': a heat producing system powered by a vertical axis wind turbine.

DAF INDAL LIMITED
3570 Hawkestone Road
Mississauga, Ontario L5C 2V8
Developing Darrieus turbines.

HYDRO-QUÉBEC
Institute of Research
1800, montée Sainte-Julie
Varennes, Quebec J0L 2P0
Experiments with compressed air storage of wind energy.
Field trials of grid-connected Darrieus turbines.

NATIONAL RESEARCH COUNCIL CANADA
Ottawa, Ontario K1A 0R6
Coordinating the Canadian government program of wind energy research, development and demonstration.

THERMAX CORPORATION
Box 275.
Hawkesbury, Ontario K6A 2R9
Manufacturing modified Savonius rotors.

UNIVERSITY OF SHERBROOKE
Department of Mechanical Engineering
Sherbrooke, Quebec J1K 2R1
Studying, among other things, wind powered heating systems, and blade materials and shapes.

Selected Readings

Books

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Periodicals

Canadian Renewable Energy News, P.O. Box 4869, Station 'E' Ottawa, Ontario, K1S 5B4.
A monthly newspaper covering developments in all renewable energy technologies.

Beaulieu, François. (1979). "Se brancher sur le vent." *Québec Science*, October 1979.

Simms, D. and O'Connel, A. (1979). "Wind Energy Sources, 1979." *Harrowsmith*, September 1979.
As the title indicates, a useful compilation of sources and information: manufacturers and distributors are listed, as well as construction plans, periodicals and books.

Wind Power Digest, 109 E. Lexington, Elkhart, Indiana, U.S.A. 46514.

This booklet is the first in the *Exploring Energy* series.

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and the National Research Council
are publishing this series to help explain how various sources of energy can be harnessed, and to report on scientific and engineering developments.

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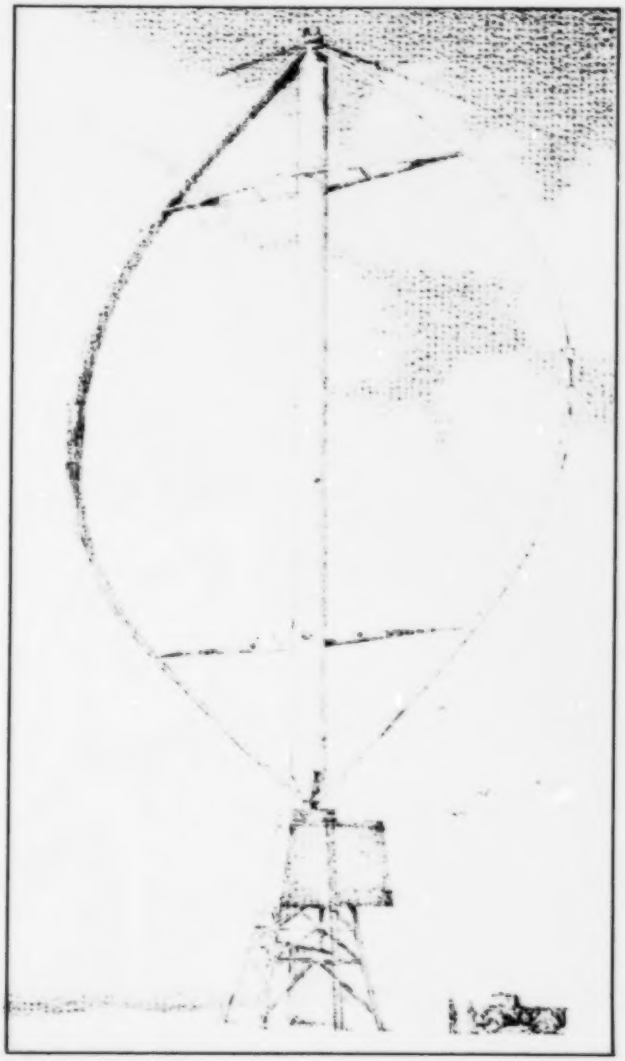

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